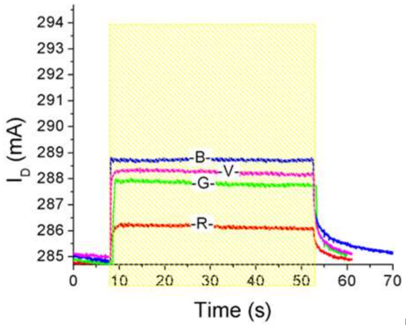
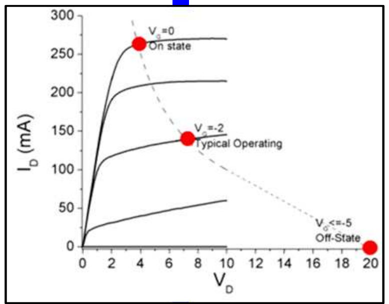
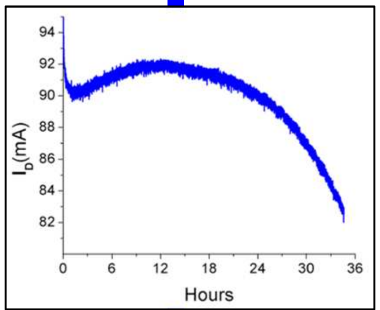
Optical pumping and final metal investigation

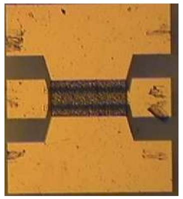
•Optical pumping
of unstressed device

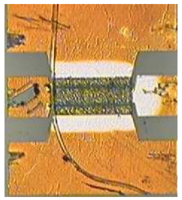


•Stressing
points

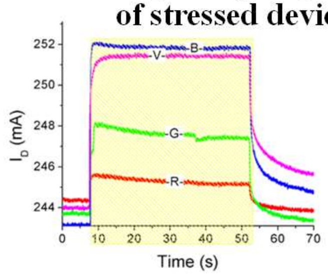




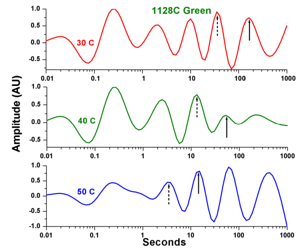




•Optical pumping
of stressed device



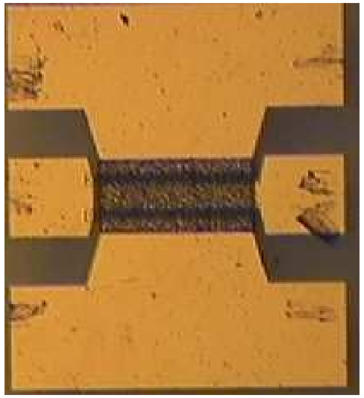
•Trap analysis



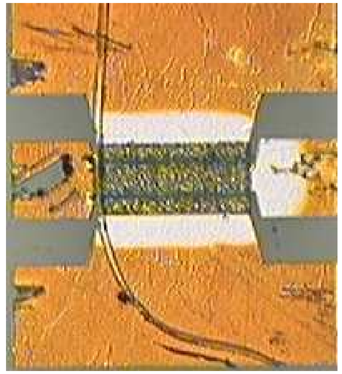
t=0, As Built

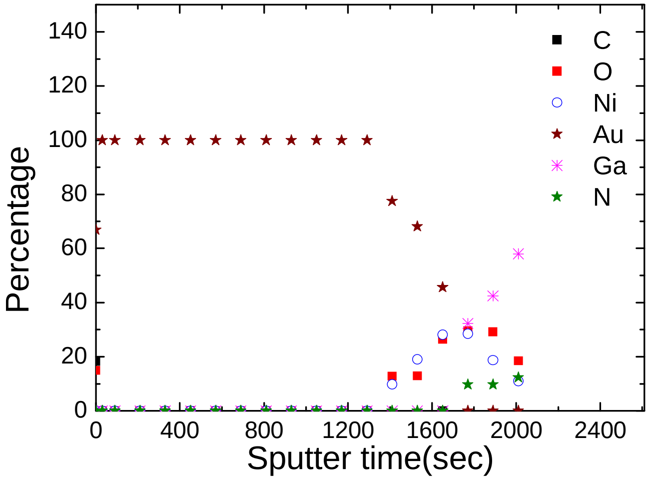
t>0, Degradation

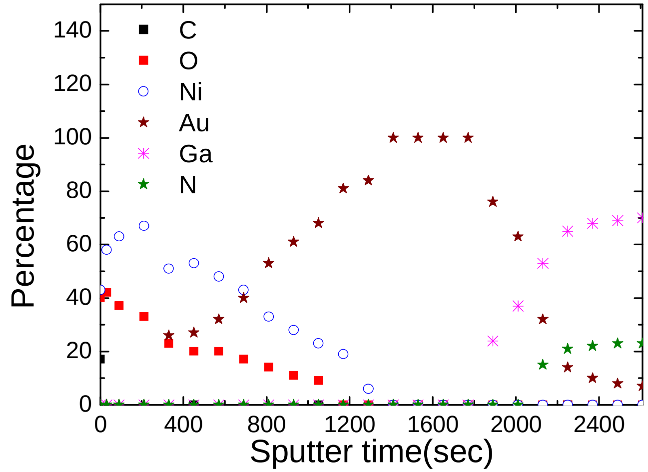
Final Metal Study



300C anneal in air

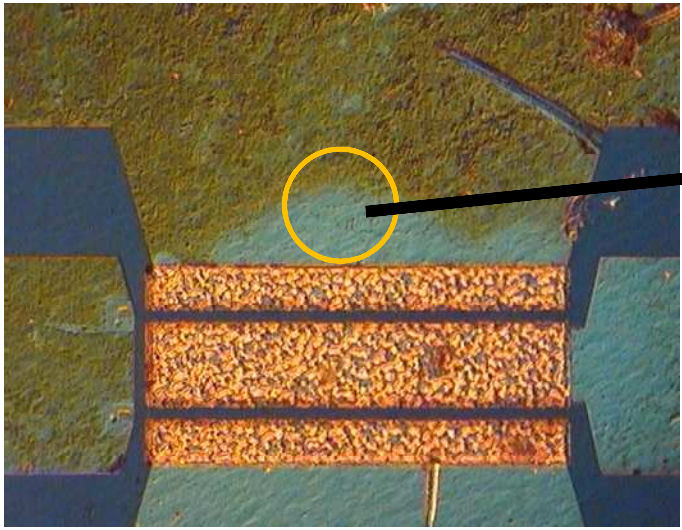


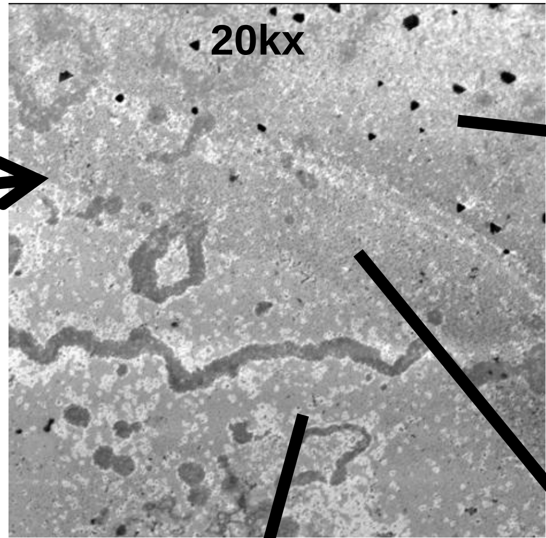


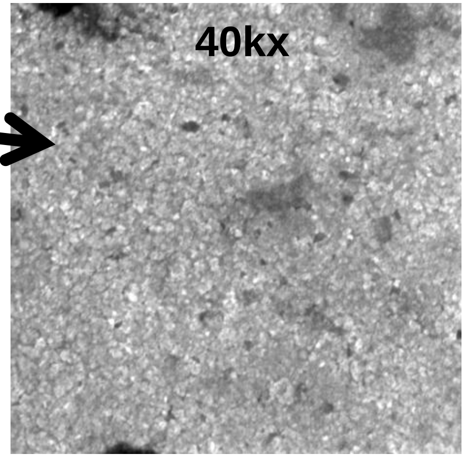


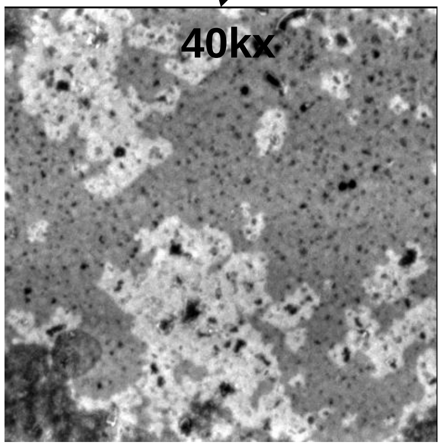
Ni/Au final metal not as robust as Ti/Au or other metal stacks

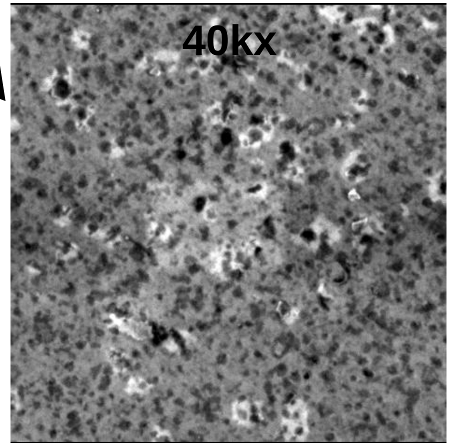
Final Metal Study











Several surface morphologies in a localized area.

Pinholes and islands

Optical Pumping Study

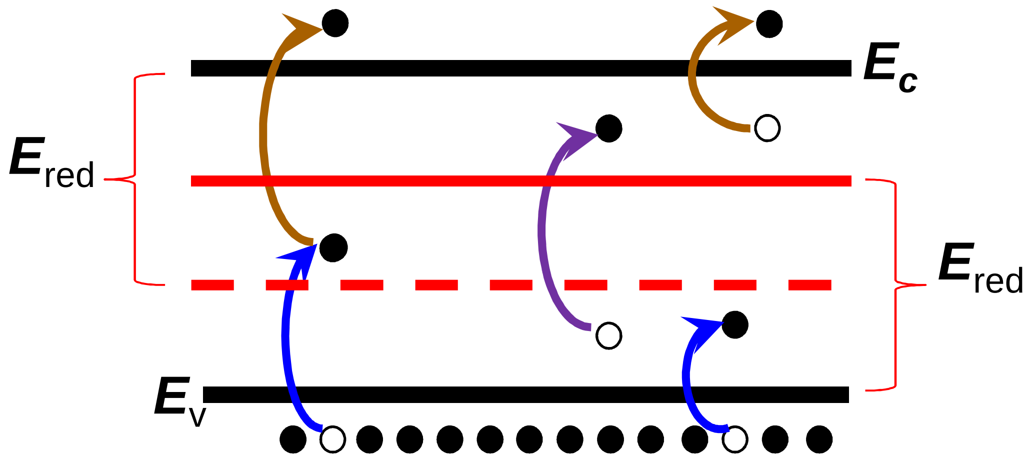
Optical pumping characterization.
- **vendor A**
- **vendor B**

Optical pumping during stress.

Optical trap measurements.

Optical Pumping Study

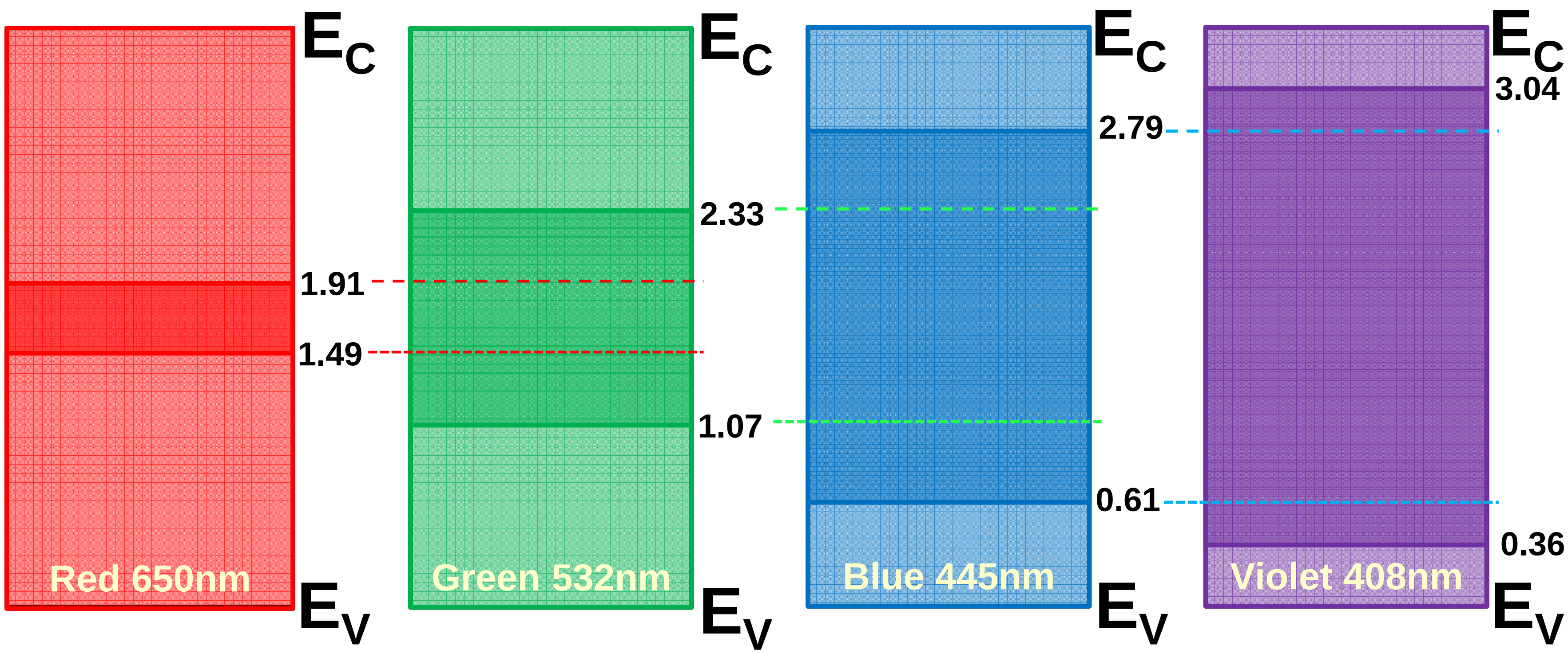
Sub band-gap illumination of traps



1. **Trap Filling:** $E_T \leq E_{red}$ **Illumination fills trap**
2. **Trap Emptying:** $E_T \geq E_c - E_{red}$
3. **Trap to trap:** $E_{T1} - E_{T2} \leq E_{red}$

Optical Pumping Study

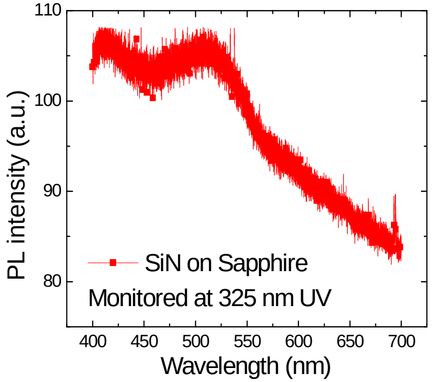
Sub band-gap illumination of traps



Considerations of optical pumping

Thermal aging (750hrs+ @ 300C in air) shows little change in I_{DS}, but severe increase in I_{GS}.

Effect of SiN cap



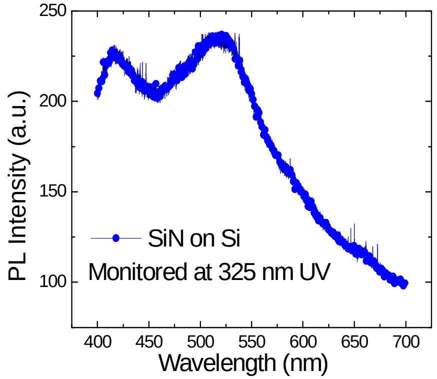


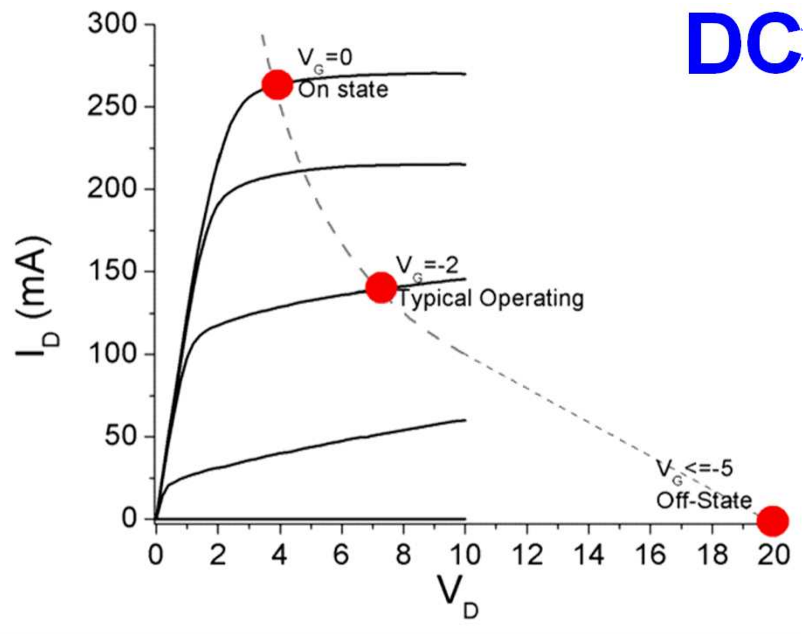
TABLE II. Effect of disilane flow rate on the optical properties of a-SiN_x :H films. PL was excited by the 457.9 nm (2.71 eV) line of Ar^+ ion laser.

Film #	Disilane flow rate (sccm)	Optical band gap (eV)	PL peak position(s) (eV)	Relative peak intensity
SQT1	1.1	4.74	2.1 & 1.92	0.07
SQT2	1.6	4.39	2.04 & 1.9	0.20
SQT3	2.1	4.17	2.06 & 1.92	0.56
SQT4	2.7	3.03	1.86	0.64
SQT5	3.2	2.43	1.76	1.0
PECVD 1	(Low silane)	5.2	2.23	0.41
PECVD 2	(High silane)	4.4	1.98	1.0

J. Appl. Phys. 77, p.6534 (1995)

UF UNIVERSITY of FLORIDA
The Foundation for The Gator Nation
Gator Engineering

Experimental



DC Stress

Maintain constant power

- $V_{GS} = 0 \Rightarrow$ channel degradation
- $V_{GS} < V_{th} \Rightarrow$ gate degradation
- $0 < V_{GS} < V_{th} \Rightarrow$ gate & channel

Channel Power Dissipation of 1Watt @ 150^{o}C

On-state	2 devices	140nm	V_{GS}=0 @ 1W
Semi-on	12 devices	125 - 170nm	V_{GS} = -2 @ 1W (typical operating)
Off-state	3 devices	125 - 170nm	V_{DS} = 20, V_{GS} = -5

DC stress until a 10% change in I_D or an order of magnitude change in I_G

Experimental

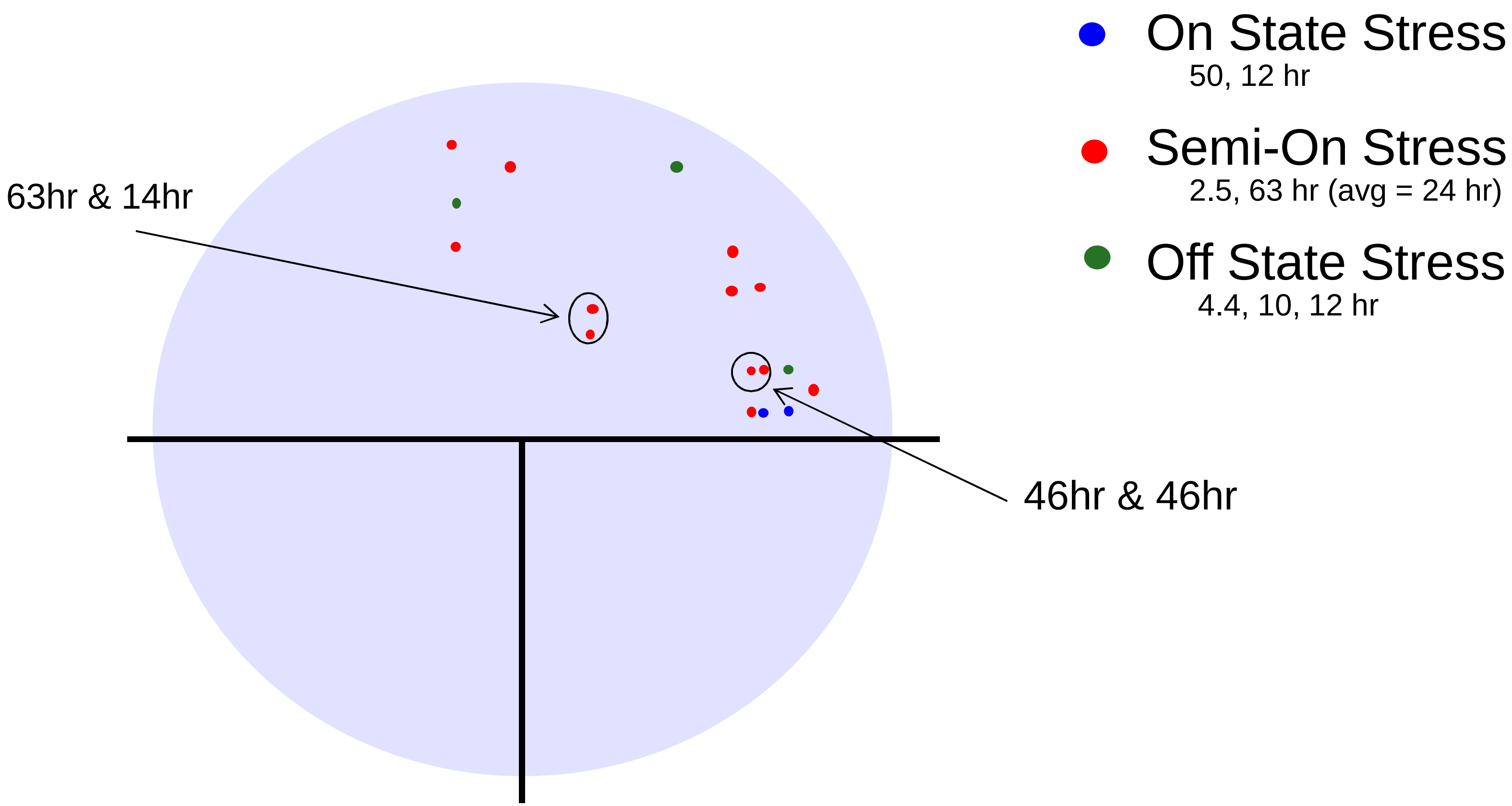
Setup

	Laser		Ev
Red	650nm	100mW	1.91 eV
Green	532nm	100mW, 300mW	2.33 eV
Blue	445nm	0.5W	2.79 eV
Violet	408nm	100mW	3.04 eV
UV	325nm	100mW	3.81 eV

Optical pumping conditions

- Bias
  $V_{GS} = 0$, $V_{DS} = 5$, 30^0C
- Continuously sample 10/100kHz
  I_D, V_D, V_G

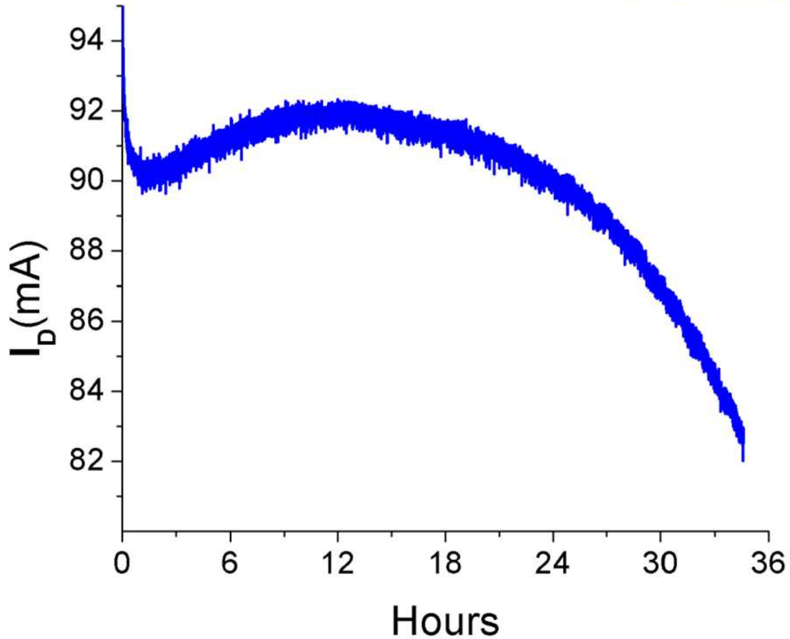
Vendor 1 Wafer Map

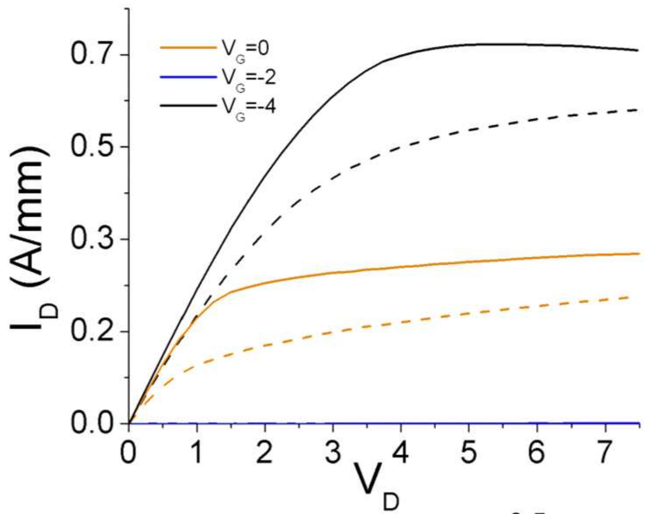


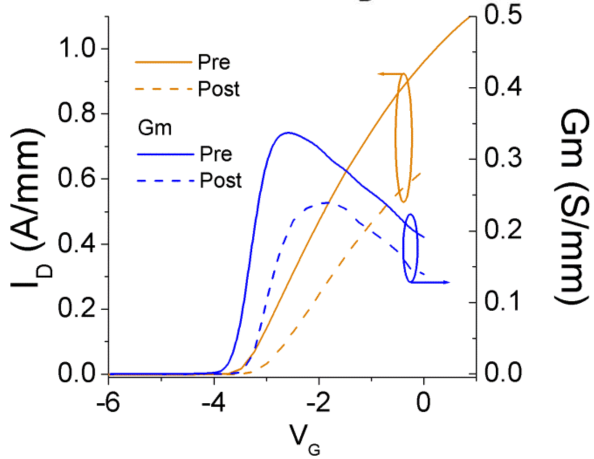
Tested 120 random reticles, 25 survived through to post packaging testing.

Thermal & Bias stressing – vendor 1

Gradual Failure



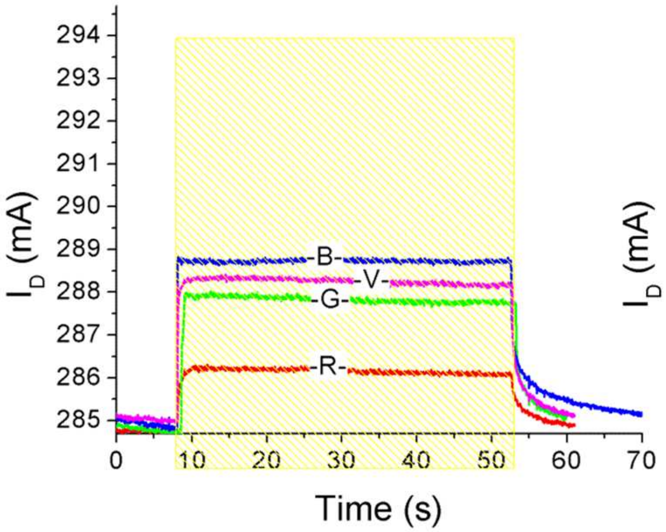




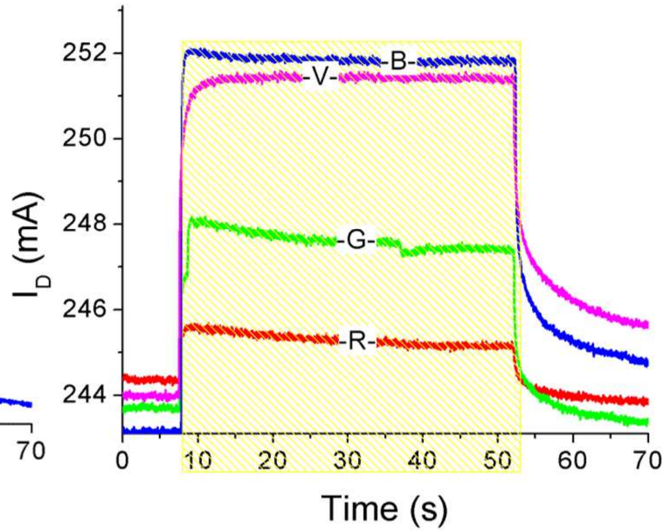
- Gradual change in drain current
- Electrical characterization shows degradation
- No increase in gate leakage current

Thermal & Bias stressing – vendor 1

Gradual Failure



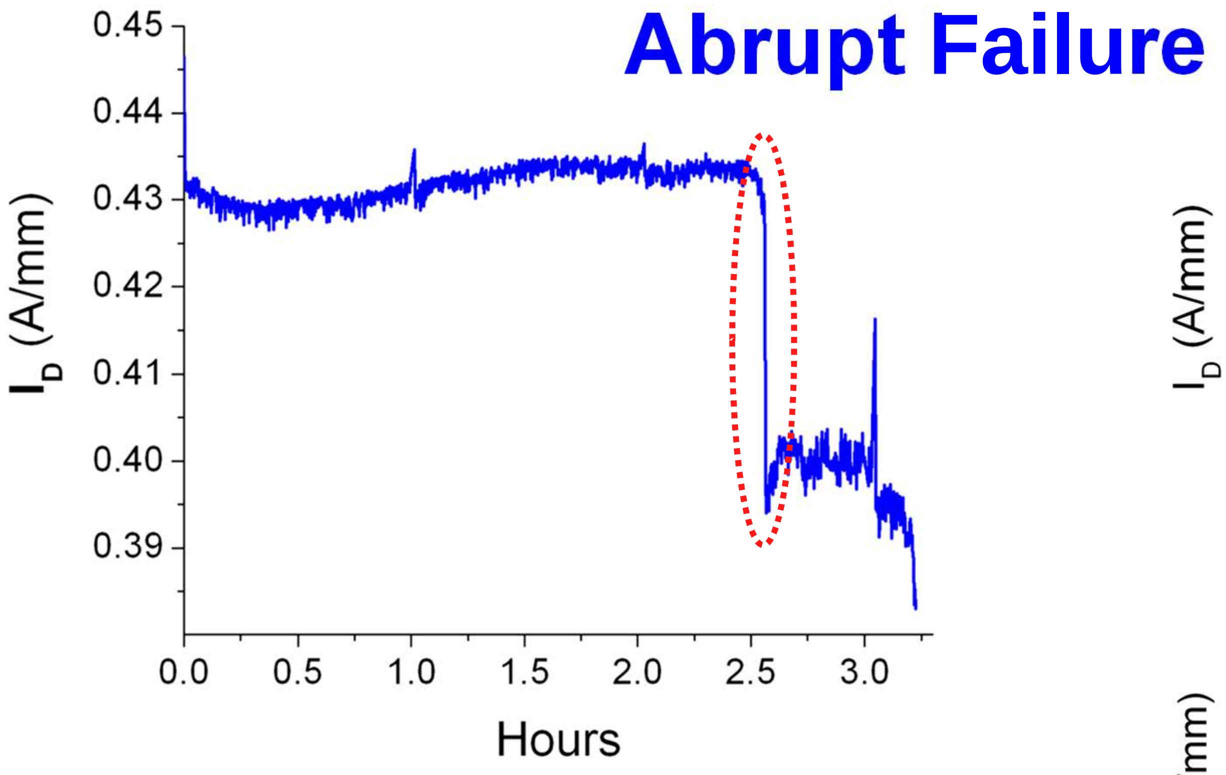
Red ~ 6.2E15/cm^3 traps
Green ~ 1.9E16/cm^3 traps
Blue ~ 2.3E16/cm^3 traps
Violet ~ 2.2E16/cm^3 traps

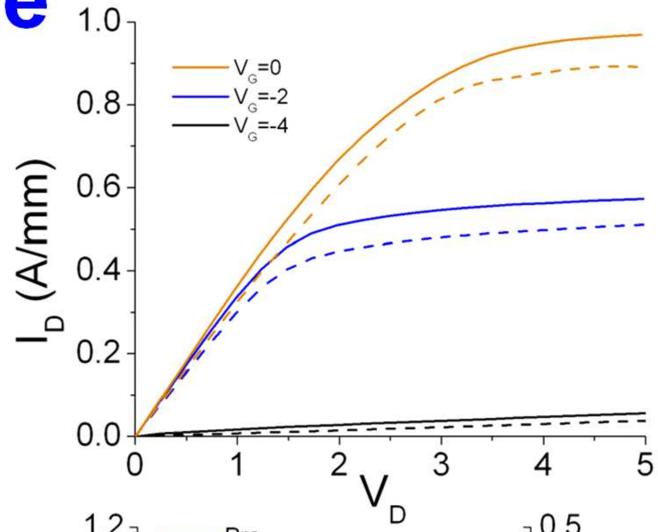


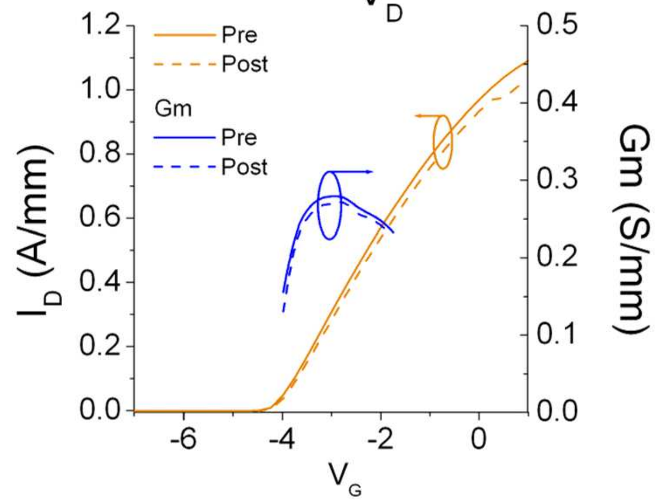
Red ~ 6.2E15/cm^3 traps
Green ~ 2.5E16/cm^3 traps
Blue ~ 5.6E16/cm^3 traps
Violet ~ 4.7E16/cm^3 traps

- Red and green change little
- Violet and blue response doubles
  Trap creation between green (2.33ev) and blue (2.79)
- Literature suggest O_N, N_{Ga}, Ga_N

Thermal & Bias stressing – vendor 1



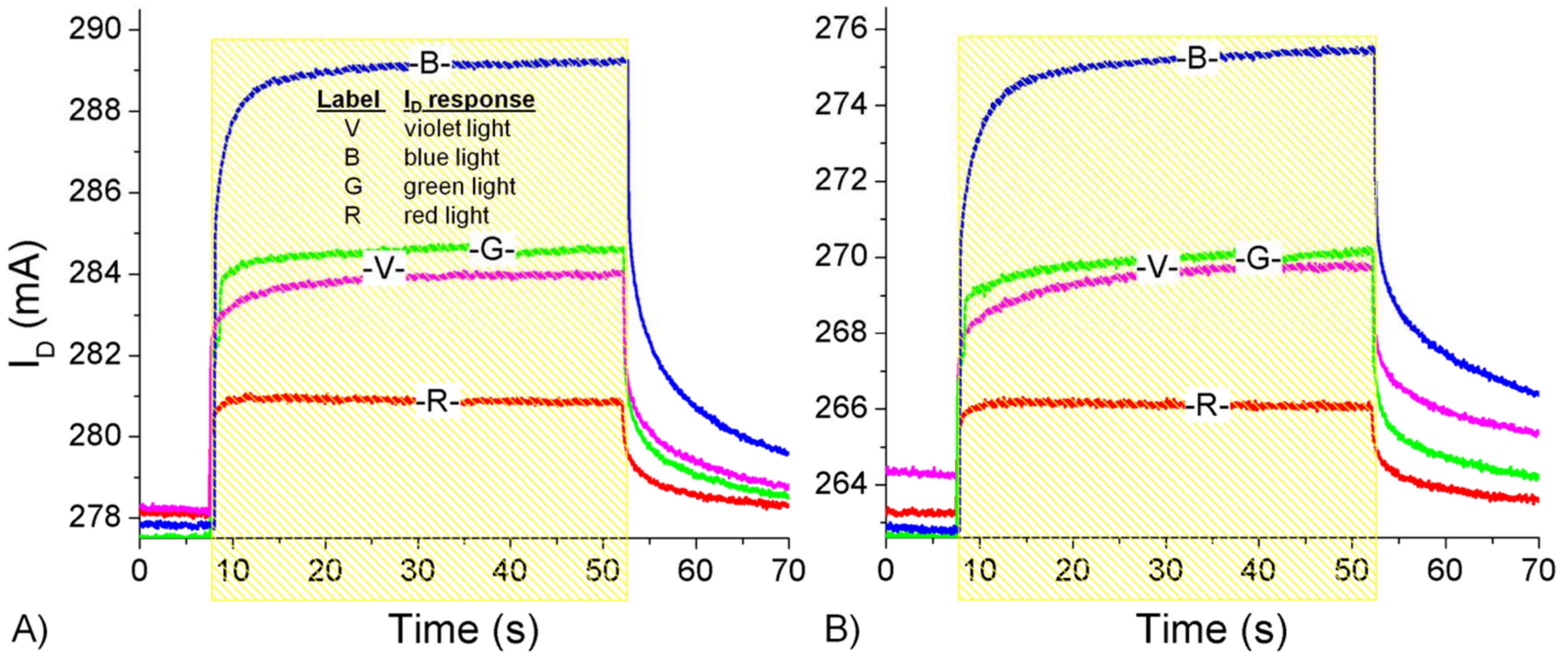




- Sharp drop in drain current
- Little degradation shown with electrical characterization
- No increase in gate leakage current

Thermal & Bias stressing – vendor 1

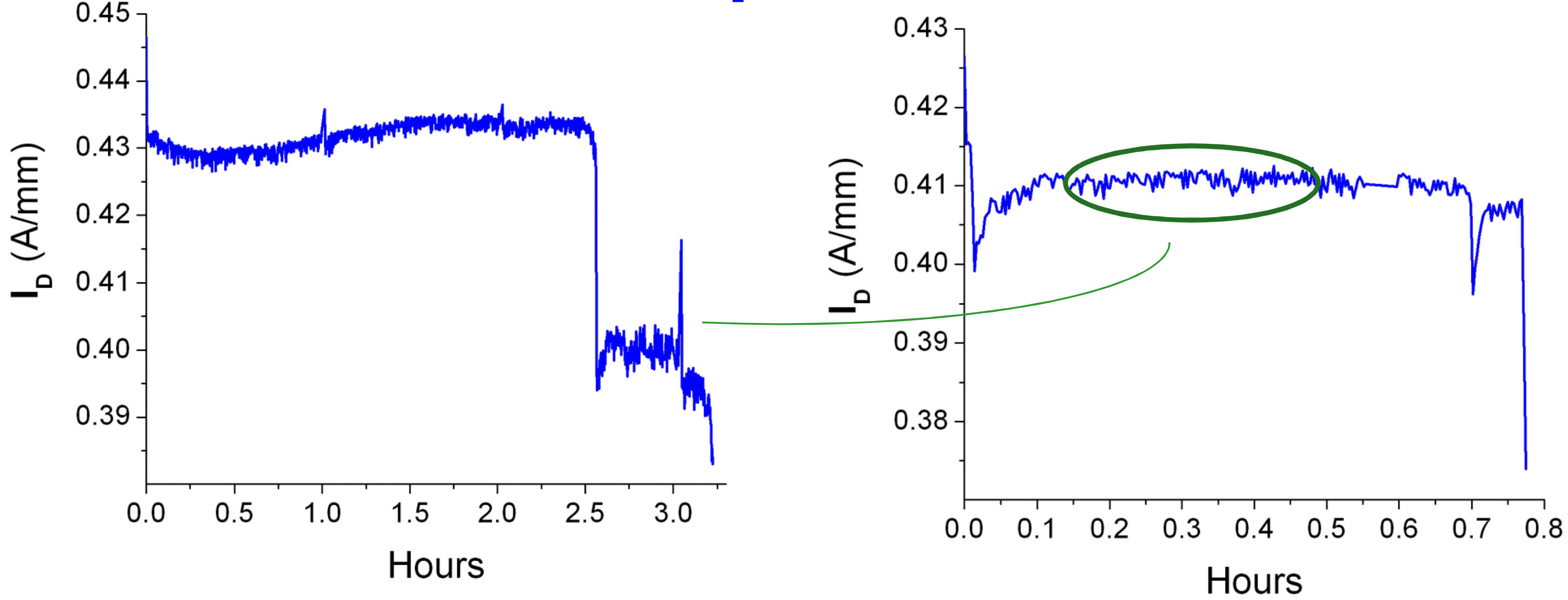
Abrupt Failure



- Little changes in optical response
- Suggests no changes in traps
- The nature of the failure points to contact failure

Thermal & Bias stressing – vendor 1

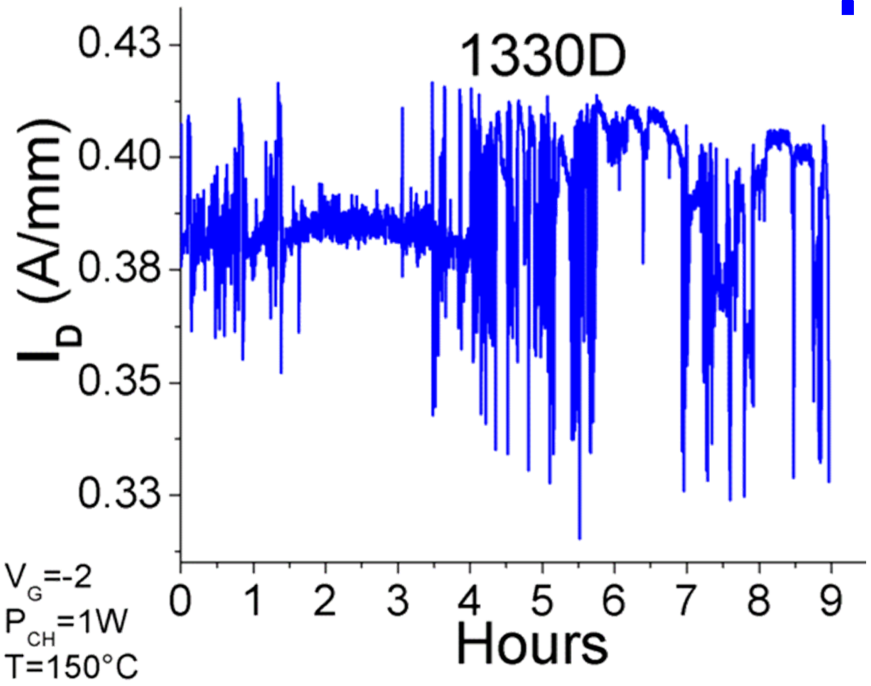
Abrupt Failure

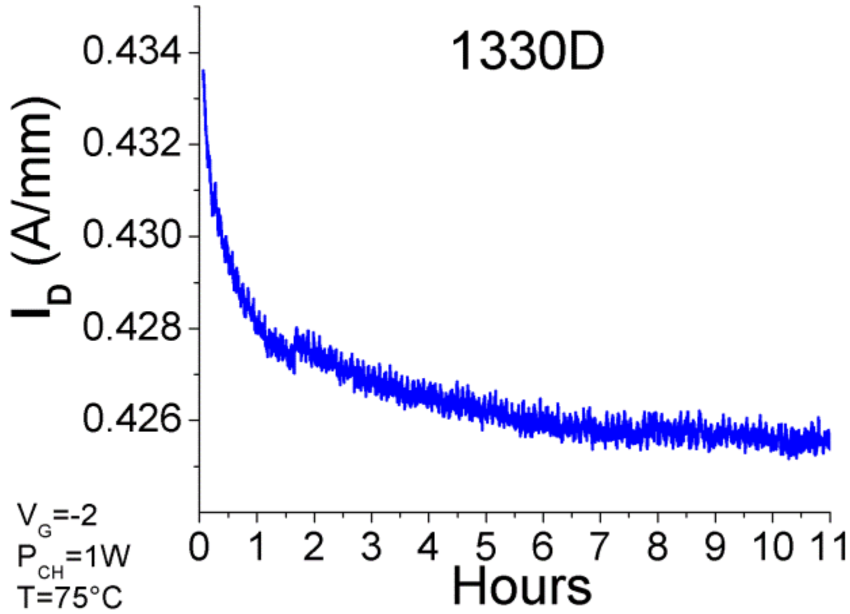


- 2nd DC test 24 hours later.
- Starts at original ID, but quickly returns to where first test dipped
- Fails quickly

Thermal & Bias stressing – vendor 1

Abrupt Failure

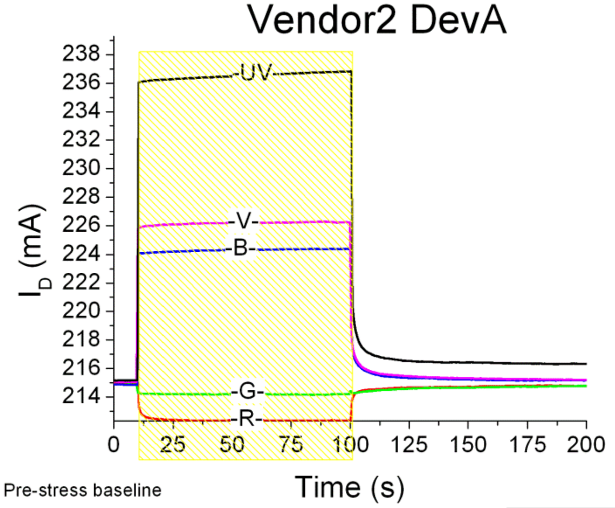




- Temperature dependence
- Not likely dislocation or point defect related
- Also points to contact failure

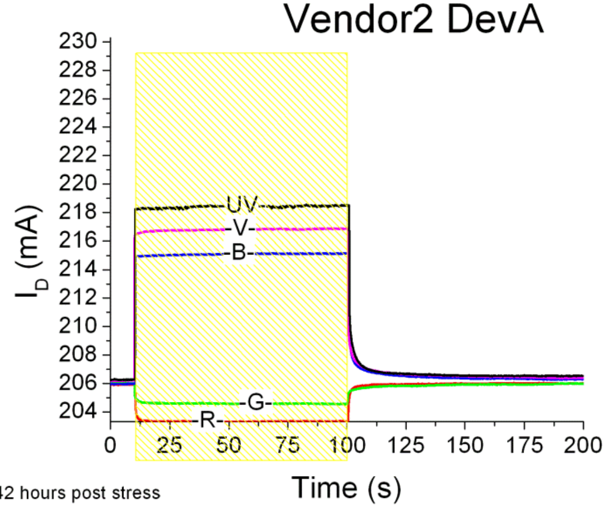
Thermal & Bias stressing – vendor 2

V_G=0 & V_D=Step stress Start 5, 0.5V incr/hour



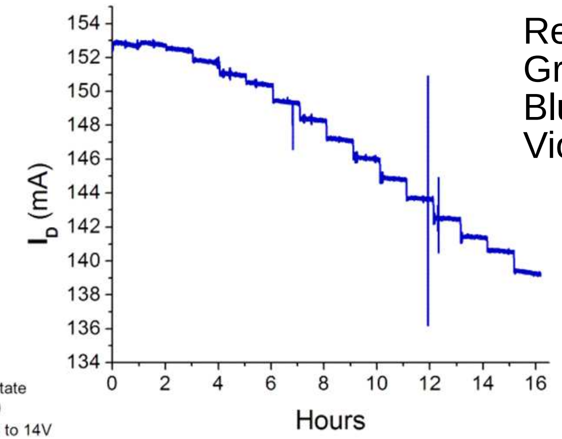
Pre-stress baseline

Red ~ 1.9E16/cm³ traps
Green ~ 6.2E15/cm³ traps
Blue ~ 5.6E16/cm³ traps
Violet ~ 6.9E16/cm³ traps



42 hours post stress

Red ~ 1.9E16/cm³ traps
Green ~ 9.3E15/cm³ traps
Blue ~ 5.6E16/cm³ traps
Violet ~ 6.9E16/cm³ traps

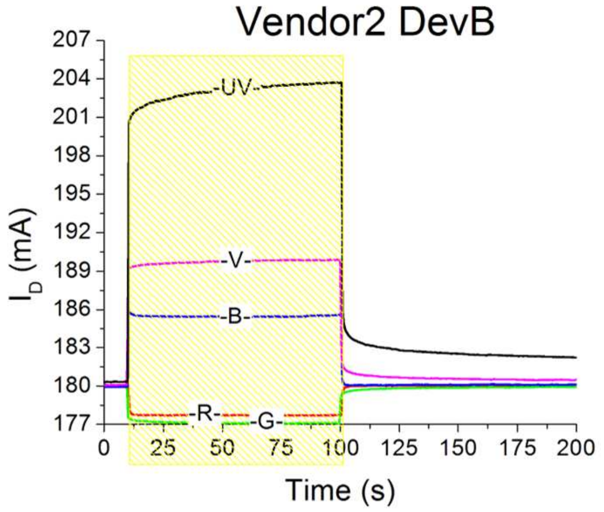


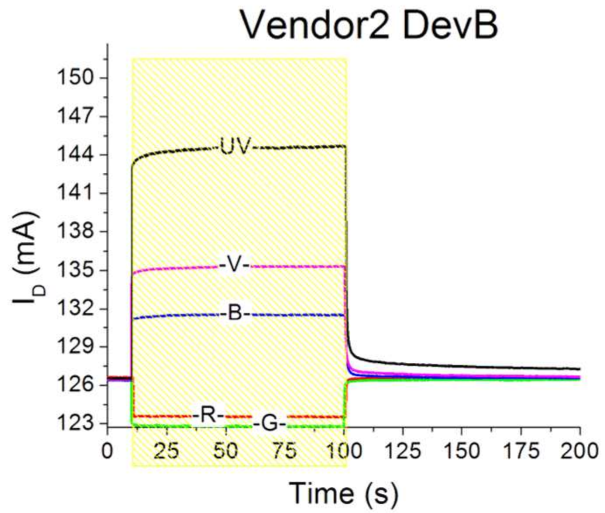
On-state
V_G=0
V_D=6 to 14V
T=150°C

•A 21st Century Approach to Reliability

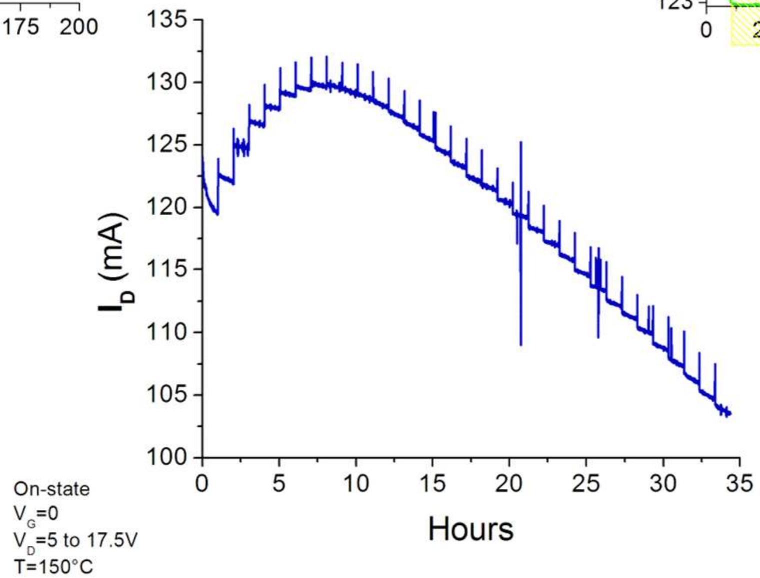
Thermal & Bias stressing – vendor 2

V_G=0 & V_D=Step stress Start 5, 0.5V incr/hour





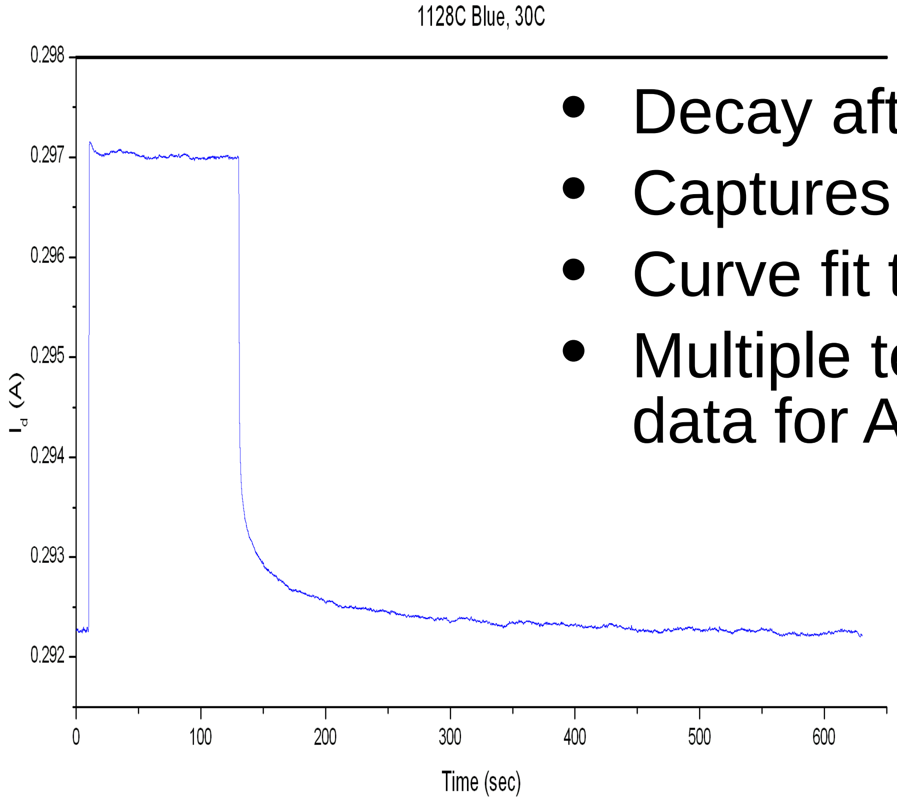
No change in trap concentration (response to illumination).



Positive shift in V_{th} and gate pulse measurements.

Trap characterization

Activation Energy



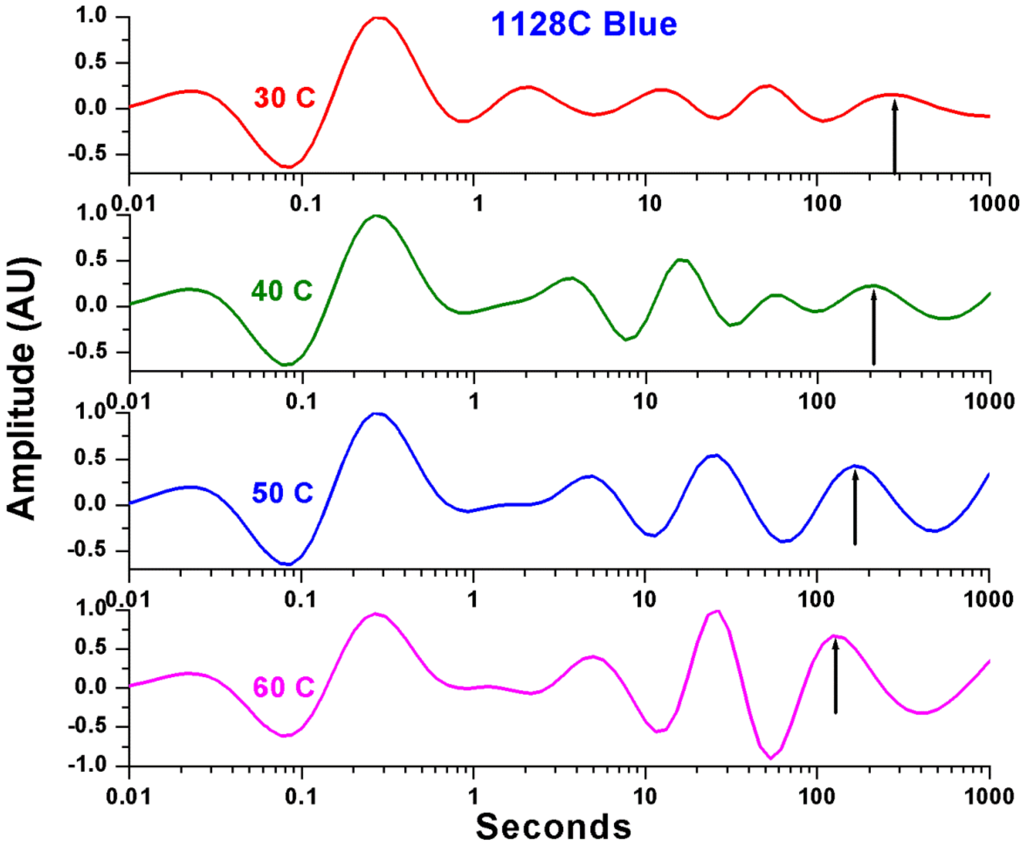
- Decay after illumination
- Captures and emission
- Curve fit to determine time constants
- Multiple temperatures for Arrhenius data for Activation Energies

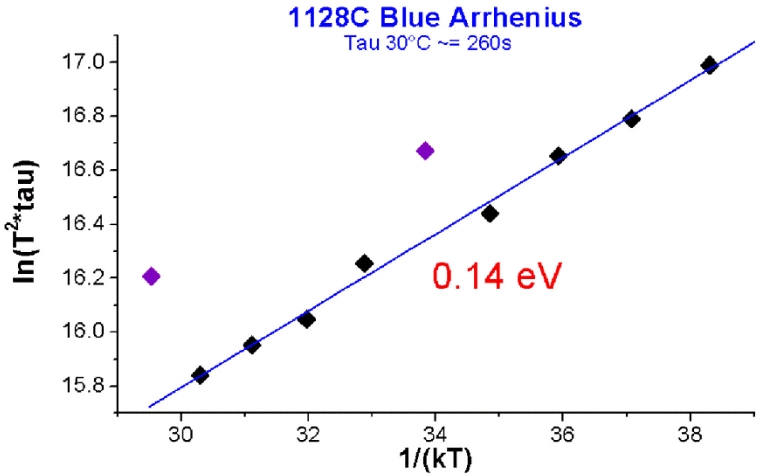
$$I_{decay} = \sum_{i=1}^{n} a_i \; e^{-t/\tau_i} + I_{ss}$$

Joh, *IEEE Trans. on Electron Dev.*, vol. 58, no. 1, Jan. 2011.

Trap characterization

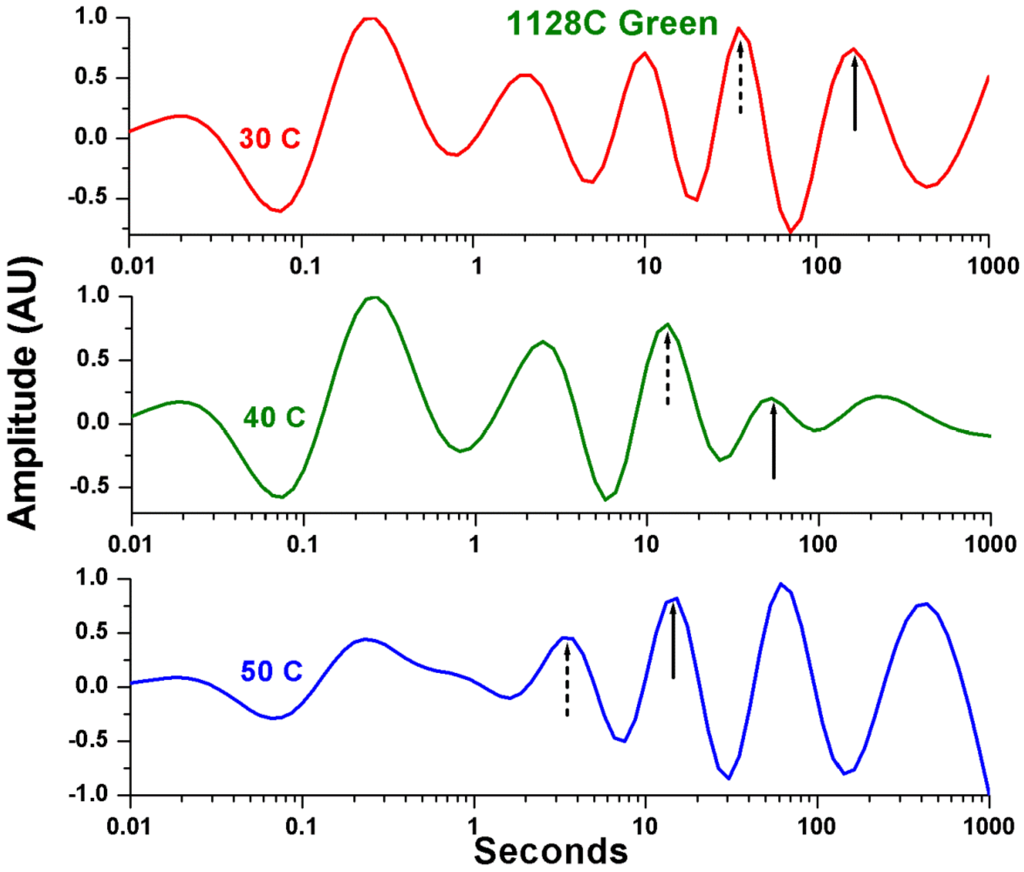
Activation Energy

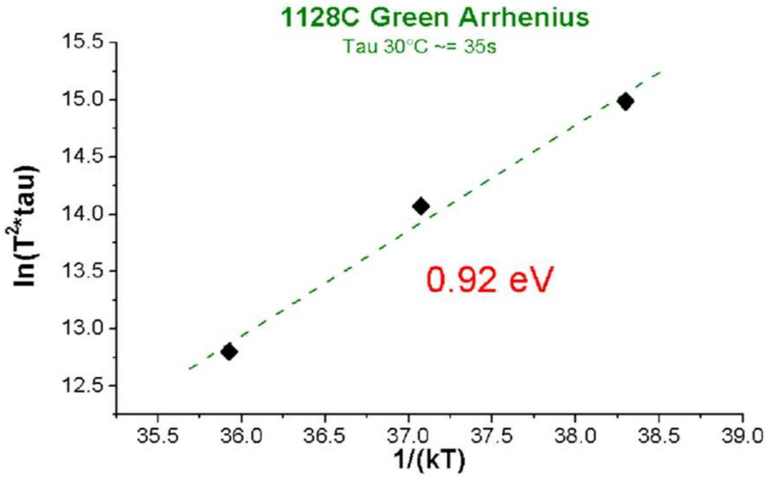


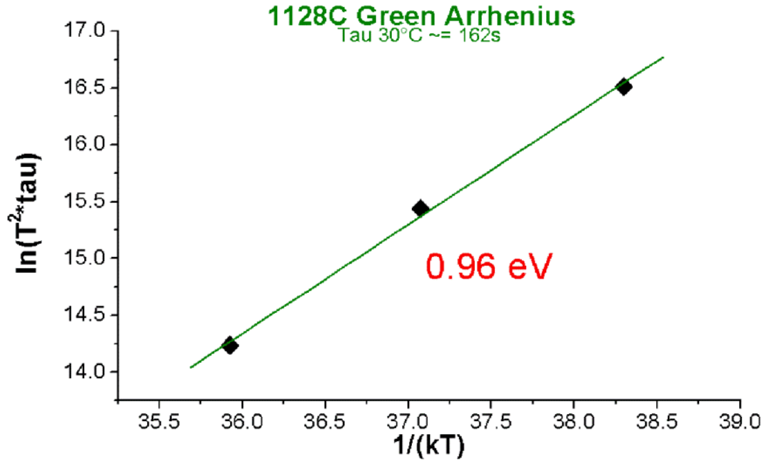


Trap characterization

Activation Energy

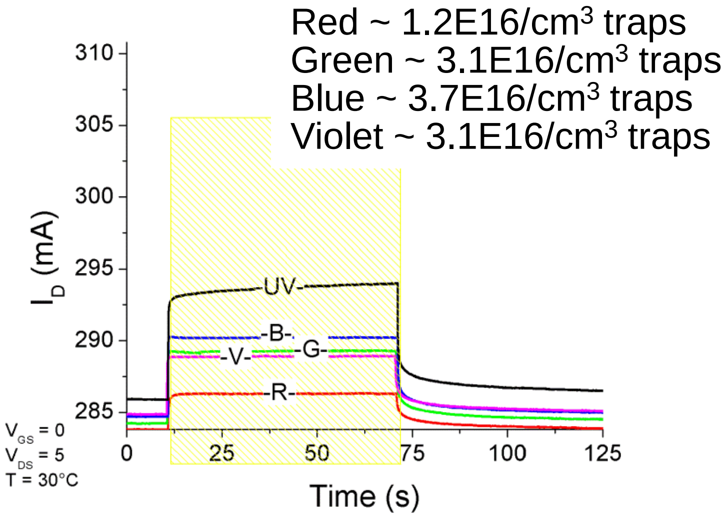


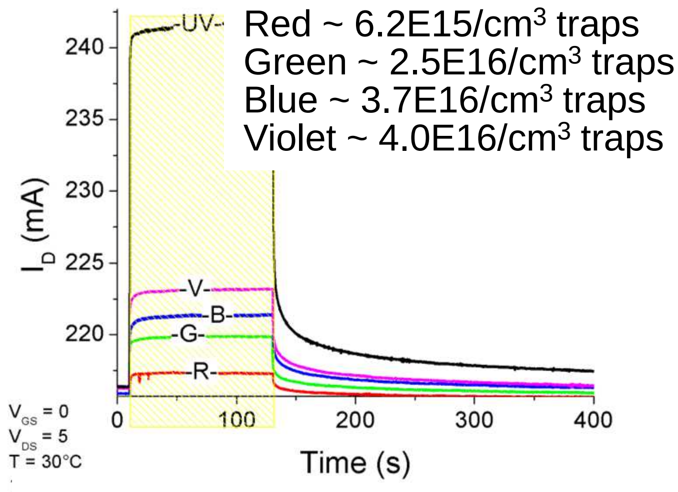


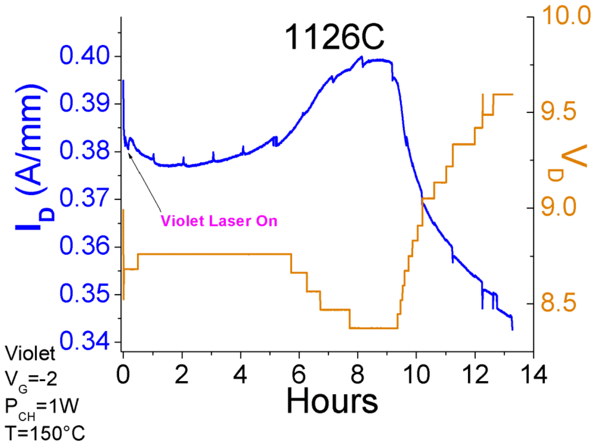


Thermal, Optical & Bias stressing – vendor 1

408nm laser illumination, Vg= -2V, P= 1W

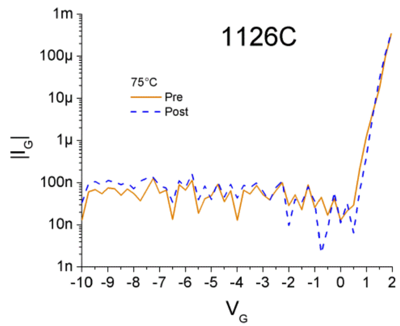






No change in V_{th}.

No change in I_g

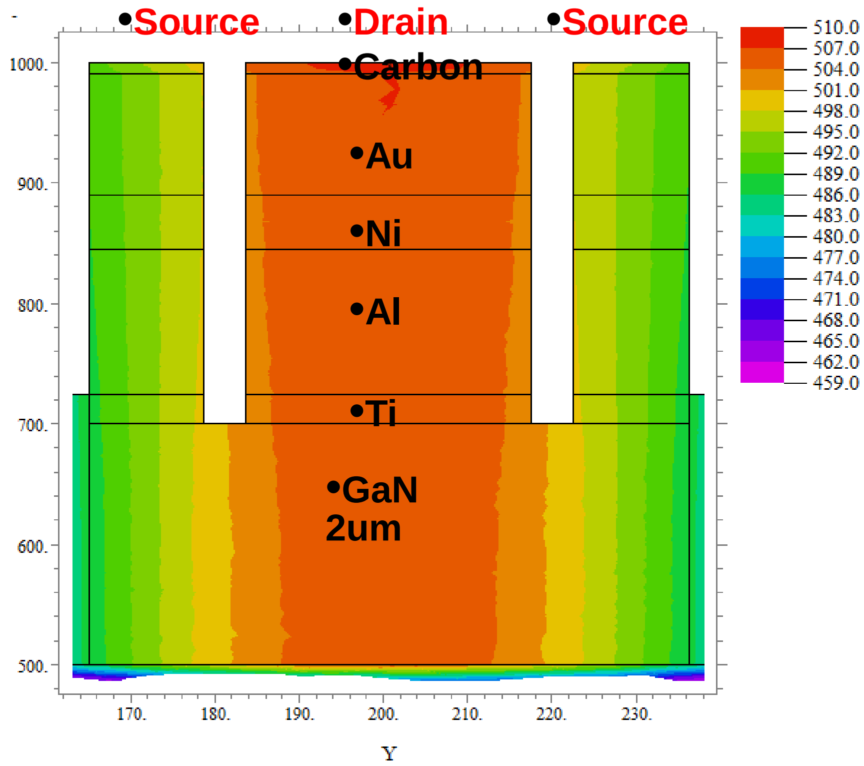


Thermal simulation of laser heating

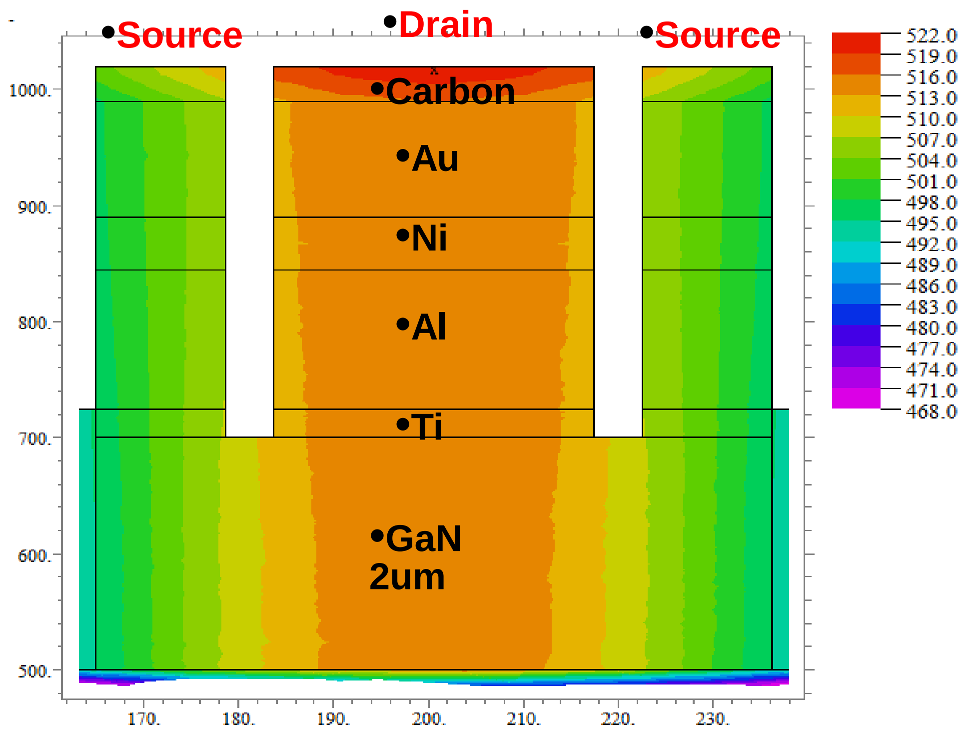
- Ti/Al/Ni/Au (250A/1250A/450A/1000A) as ohmic stack
- 1mm by 1mm SiC substrate
- The blue laser is labeled as 1000mW MAX and 500mW Min
- 750mW blue laser focused down to 150um as diameter

Use FIB with Au beam to deposit carbon onto the gate.

Thermal simulation of laser heating



100nm Carbon



300nm Carbon

Simulation without carbon shows ~440K drain temperature.

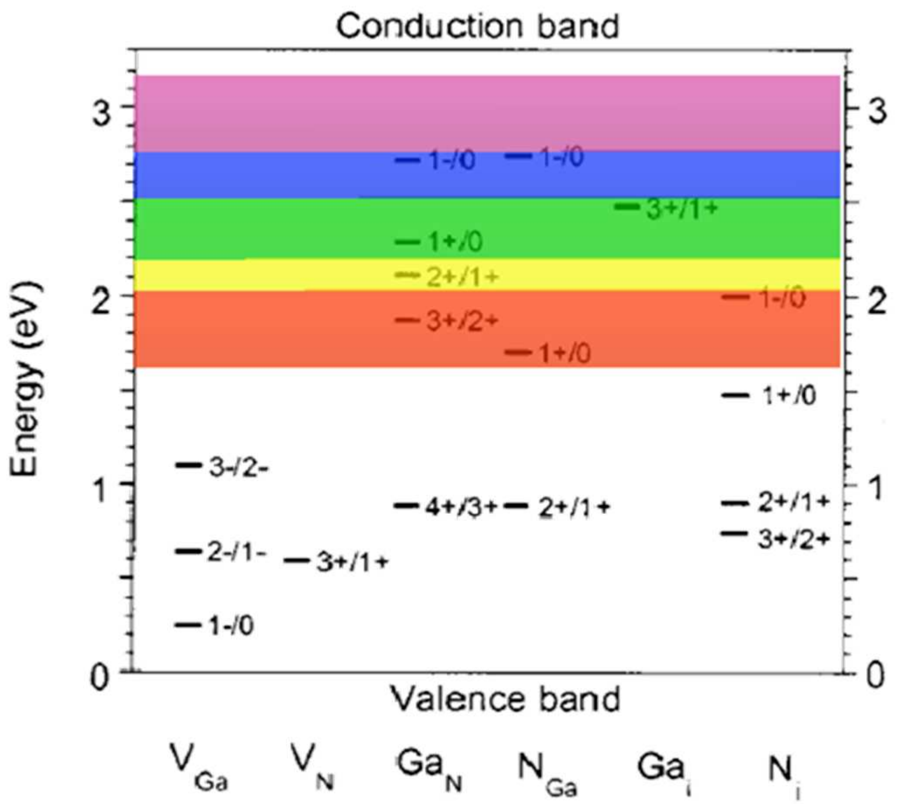
On-going Research

- Sub band-gap illumination
  - Under DC-stress
  - Lag measurements

- Location specific heating from carbon and laser.
- Optical characterization from backside and de-processed devices.

Background

Point Defects/Energies in the GaN Band-gap

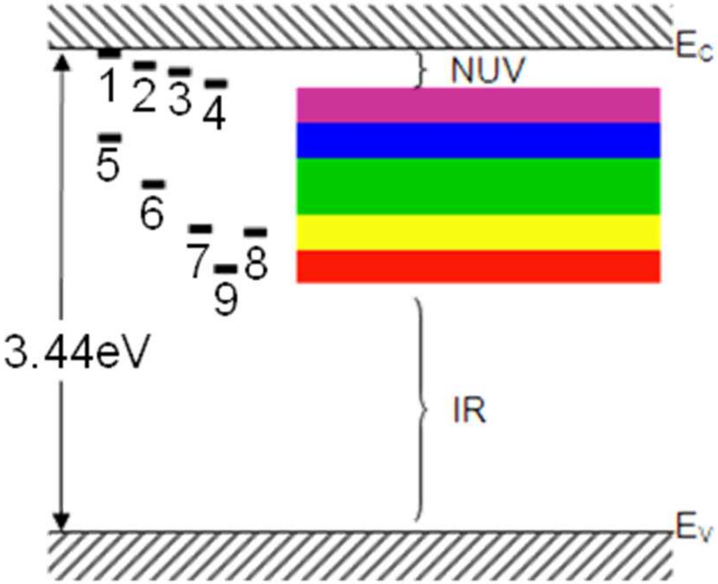


Transition levels for native defects in GaN, determined from formations energies.

Limpijumnong and Van de Walle; Phys. Rev. B 69 (2004)

Background

Point Defects/Energies in the GaN Band-gap



Defect	eV	Description
1	3.41	basal plane stacking faults [1-2] a-type threading dislocations [3]
2	3.34	a-plane stacking faults [1]
3	3.28	partial dislocations [1]
4	3.20	C_N [4]
5	2.9	Blue defect - O_N, dopants [5]
6	2.5	Green defect - dopants [5]
7	2.2	Yellow defect - several vacancy defect models, V_{Ga} bound to dislocation, dopants [5]
8	2.21	edge dislocations (screw dislocations are invisible) [6]
9	1.8	Red defect - V_NC_N, dopants [5]

1. R. Lui et al; APL 86, 021908 (2005)
2. Z.H. Wu et al; APL 92, 171904 (2008)
3. M Albrecht et al.; APL 92, 231909 (2008)
4. C. Diaz-Guerra et al.; JAP 100, 023509 (2006)
5. M.A. Reshchikov and H. Morkoc; JAP 97, 061301 (2005)
6. N. Yamamato et al; JAP 94(7), 4315(2003)
7. A. Istratov, O. Vyvenko; Review of Scientic Insturments, Vol 70, Num 2 (1999)